Astrobee

2022

Destination Space 2022

“Astrobee, A free flying robot on ISS”

Jose Benavides, Astrobee Facility PM

Jose Benavides Bio/Background

- Jose Benavides is currently the Project Manager for the ISS Astrobee Facility, operated out of the Intelligent Systems Division of NASA Ames Research Center
- He will be sharing an overview of the Astrobee Facility and it' many accomplishments on ISS
- Astrobee is also a platform for STEM education and some highlights will be shown of its student outreach
- He is always looking to leverage leading edge technology to inspire others towards space exploration

Jose Benavides Bio/Background

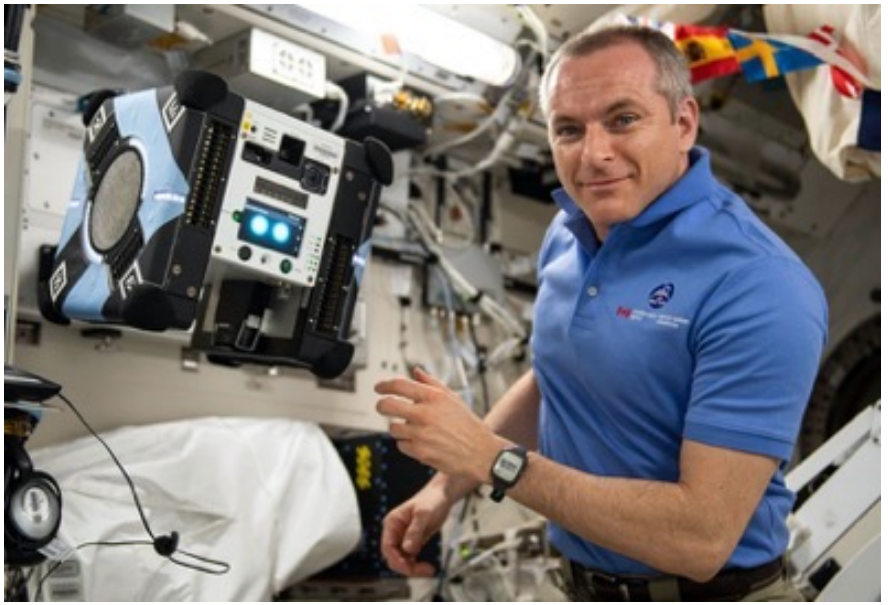
- Jose started employment as a contractor at NASA's Ames Research Center California's Silicon Valley in 2008 as a member of the Advanced Control and Evolvable Systems (ACES) Group in the Intelligent Systems Division.
- Jose is currently the Project Manager of the NASA International Space Station (ISS) Astrobee Facility project. In conjunction with the prior platform, SPHERES. the [Astrobee Facility is one of the most used and popular ISS National Lab Facilities with over 80 on-board test sessions and 400+ hours of Facility Console activities involving crew.
- His past projects include rapid prototyping of controls systems using FPGAs, controls-oriented vehicle design of air-breathing hypersonic aircraft, trajectory generation and optimization for tactical flight management systems, pilot-in-the-loop high fidelity 6-dof flight simulation, and small satellite software. His research interests include embedded systems, rapid prototyping of control systems, spacecraft, small satellites, robotics, and human-machine interaction (HMI).
- He has a bachelors and masters degree from Arizona State University in Electrical Engineering, with specialization in control systems. His hobbies include reading, hiking, dancing, and computer networking.

Astrobee Objectives

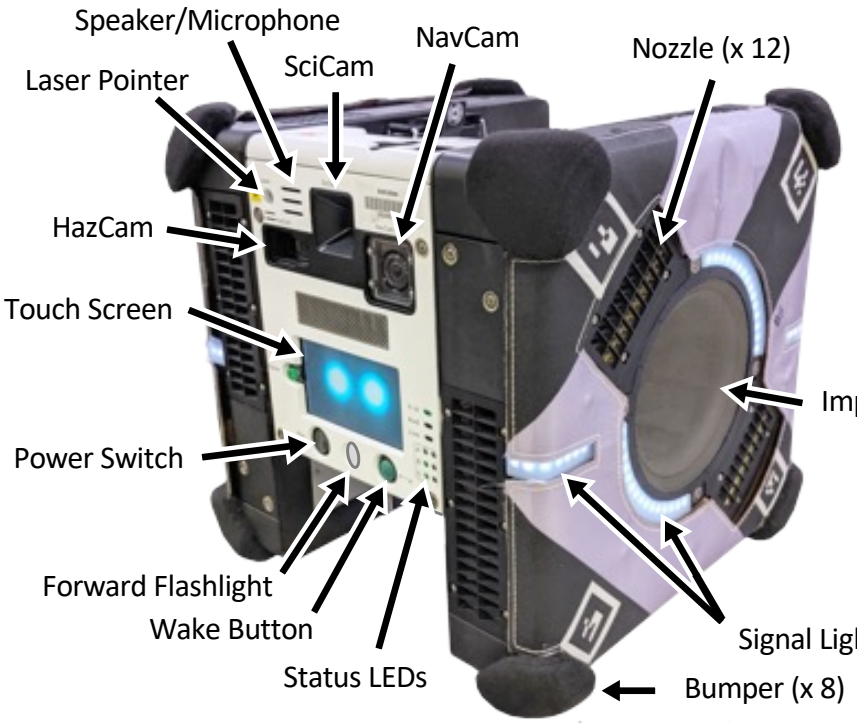
- Provide a microgravity robotic research facility in the ISS US Orbital Segment (USOS), which will replace the existing SPHERES facility
- Provide remotely operated mobile camera views of the ISS USOS to enhance the situation awareness of mission control
- Perform mobile sensor tasks in the ISS USOS

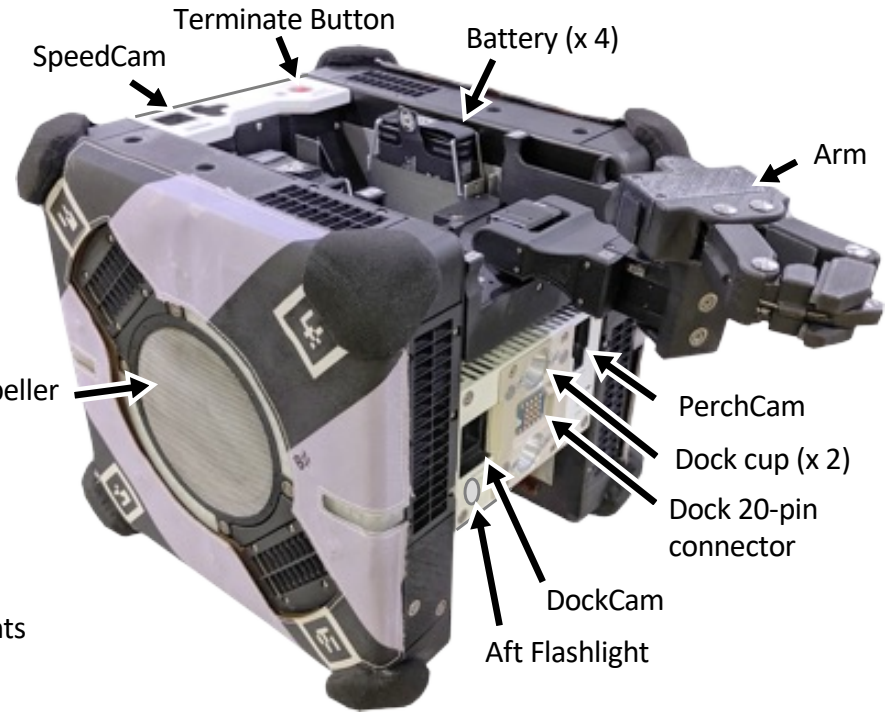
Astrobee Purpose

- Objectives
  - Provide a microgravity robotic research facility inside the ISS US Orbital Segment (USOS), which has replaced the existing SPHERES facility
  - Demonstrate feasibility of intra-vehicular robot caretaking for future human exploration vehicles
  - Provide an opportunity for future automation of certain ISS operations
- Driving use cases
  - Guest science experiments
  - Remotely operated mobile camera
  - Sensor surveys



System Description - Hardware



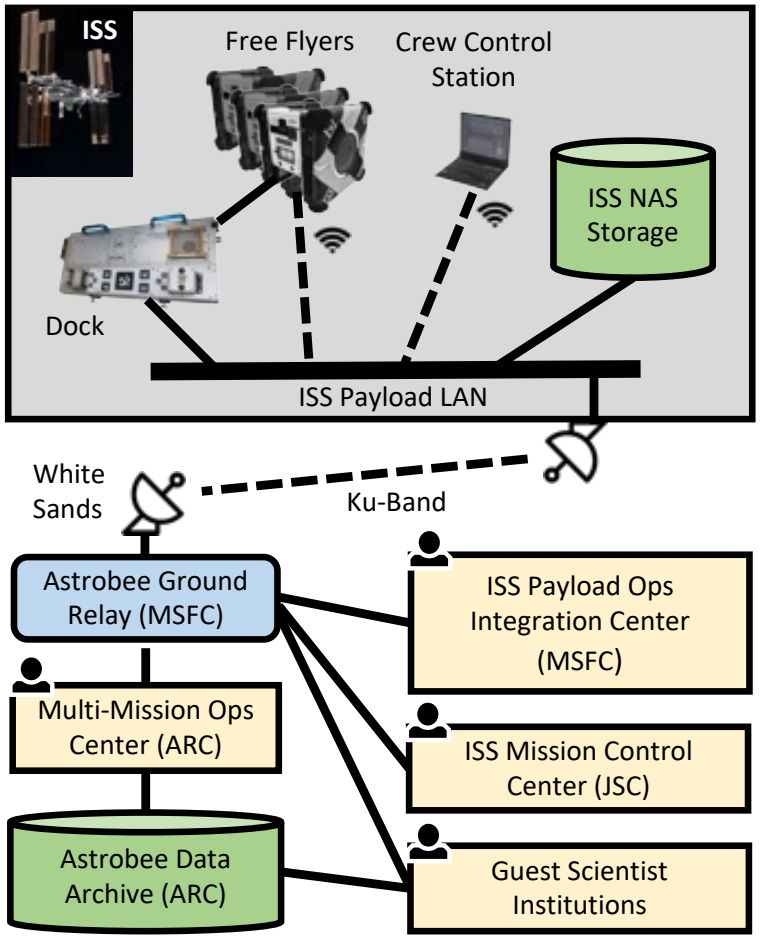


- Free flying robot inside the ISS
- 32 cm wide, ~9.1kg (2 batt., no arm)
- All electric + fan-based propulsion
- Robot arm for “perching”, ~1kg

- Three smartphone computers
- Three payload bays for expansion
- Microphone not currently enabled

System Description - Communications

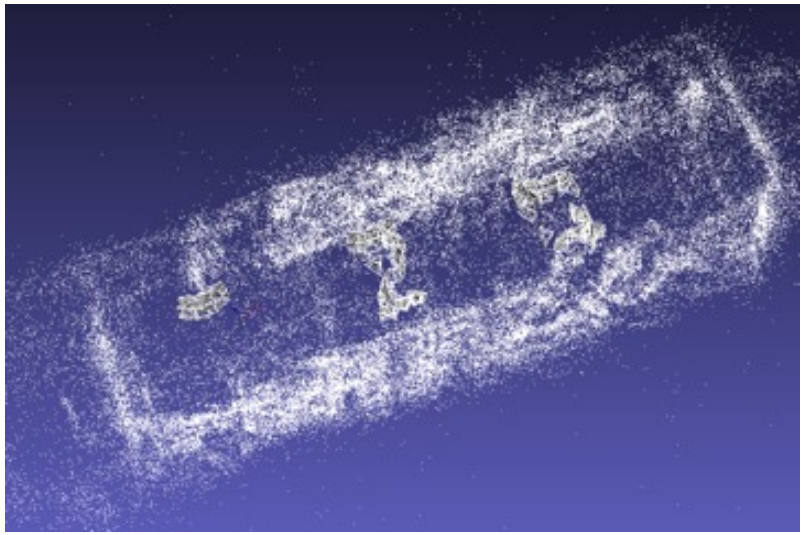
- Communicates through ISS WiFi when flying
- Single telemetry/video stream to ground
- Multiple ground stations can connect through server
- Large file transfers and software updates through Ethernet on the dock



Astrobee communications path

System Description - Navigation

- Vision-based navigation
  - Compares features with on-board a priori map
  - Incorporates inertial measurements
- Fiducials used for autonomous docking
  - Requires approximately 1 cm position accuracy
- Visual odometry
  - Robot can continue to navigate where no map features are recognized

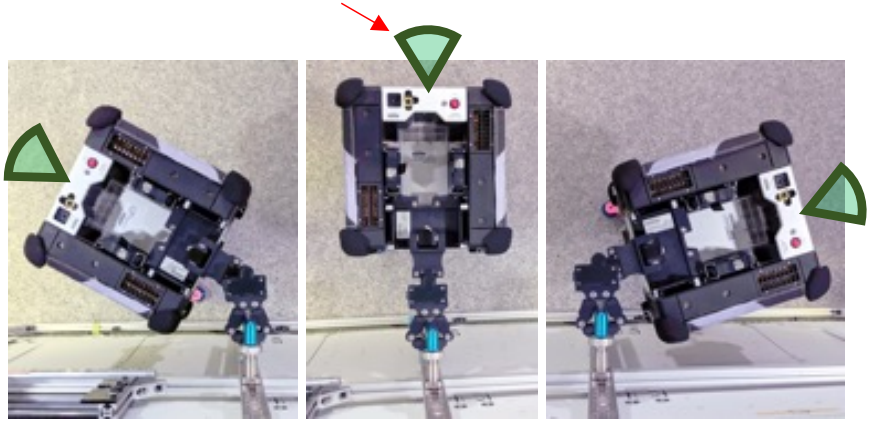


Feature map of the JEM-PM

System Description - Perching Arm

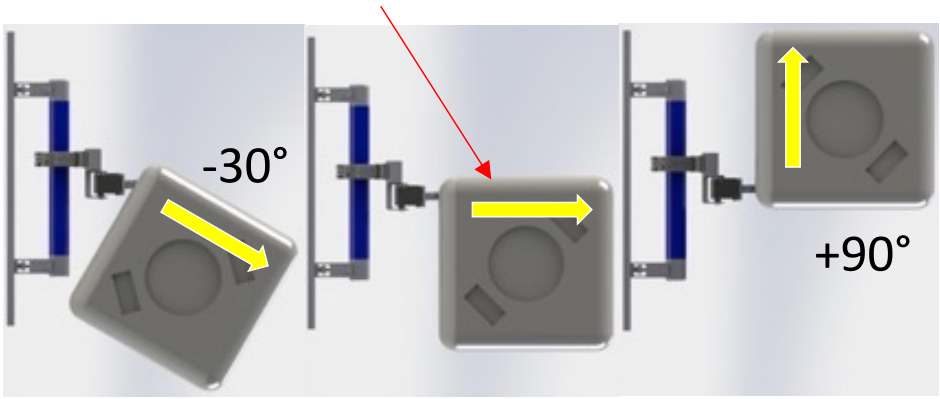
- Designed to grasp handrails
- Stows completely in payload bay
- Acts as a pan-tilt unit while perched
- Flexible and back-drivable
- May be perched manually

Camera View Direction



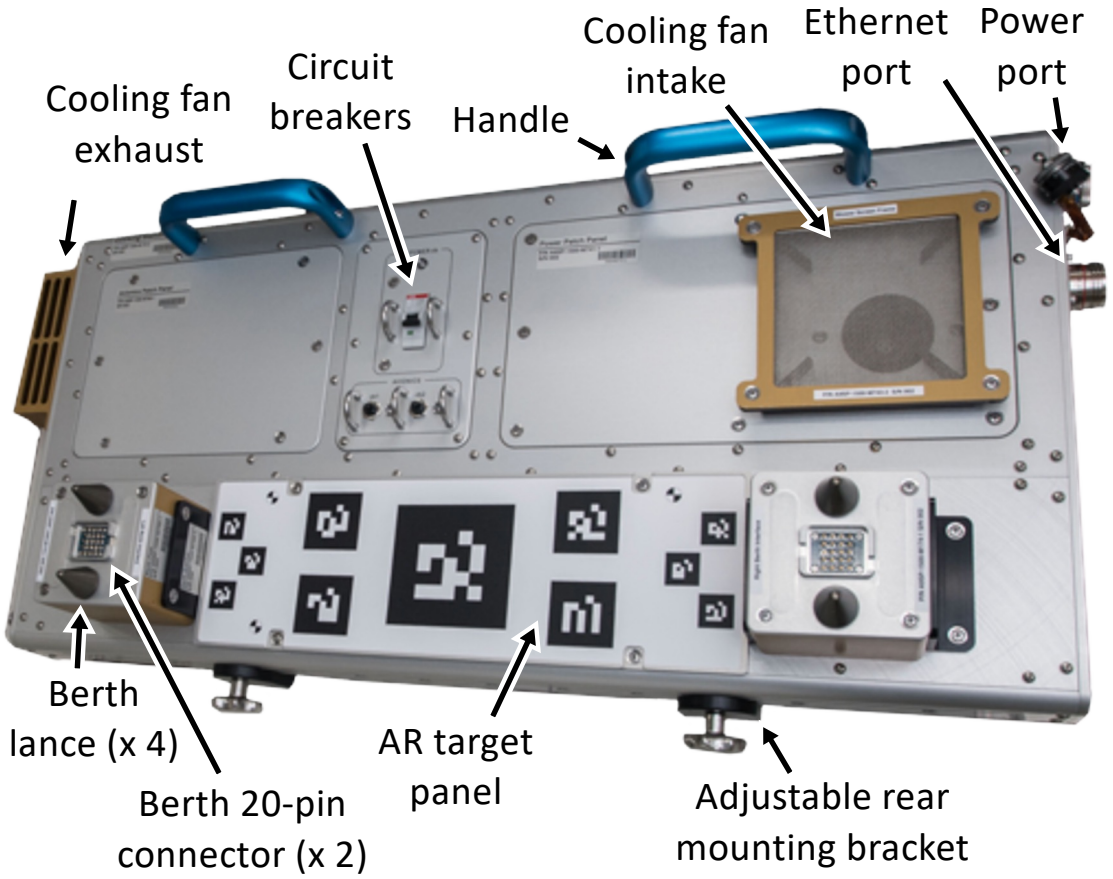
Astrobee Perching Arm pan motion

Camera View Direction



Astrobee Perching Arm tilt motion

System Description - Docking Station

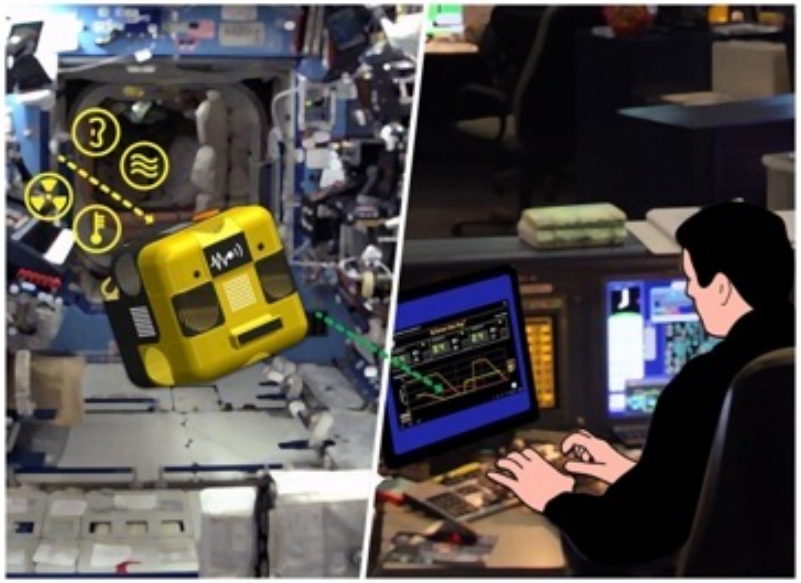


- 85 cm x 38 cm x 28 cm
- Berths for 2 free flyers
- Provides power and Ethernet

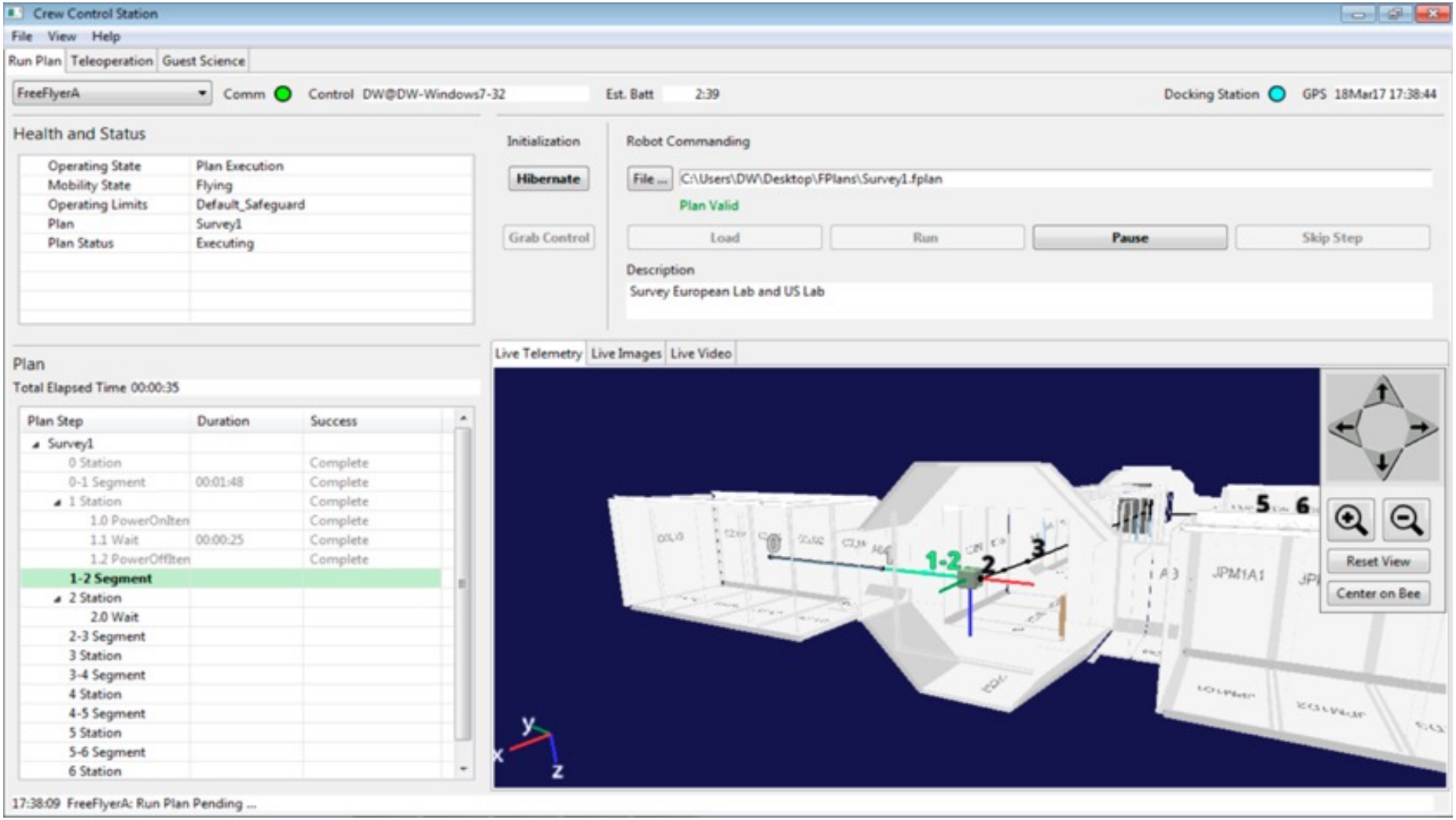
- Fiducials used for visual servoing to autonomously dock
- Magnets provide retention force

System Description - Ground Data System

- Astrobee Control Station
  - Sortie planning tool
  - Execution monitoring
    - Live telemetry
    - Image and video streams
    - 3D virtual display
  - Supervisory control (run plans or single commands)
  - Typically used by ground operators
- Crew Control Station runs on an EXPRESS Laptop Computer (ELC)
- Server for archiving and distributing Astrobee data
- Suite of engineering tools to support maintenance and software upgrades



Astrobee Control Station

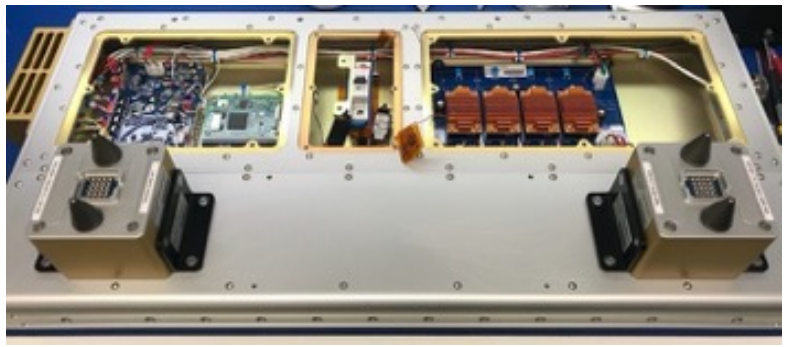


Basic Conops

- When an Astrobee is idle, it charges in its dock
- Astrobees can execute complex plans with full autonomy and no astronauts present
  - Including undock, traverse multiple modules, return to dock
- However, Astrobees run with ground operator oversight
  - When an anomaly occurs, an Astrobee generally stops and waits for operator intervention
  - It can continue operating during communication outages until it encounters an anomaly
- The operator can always take over and teleoperate
- Astronauts can also be operators, but this is will likely be a rare occurance (minimize crew time)

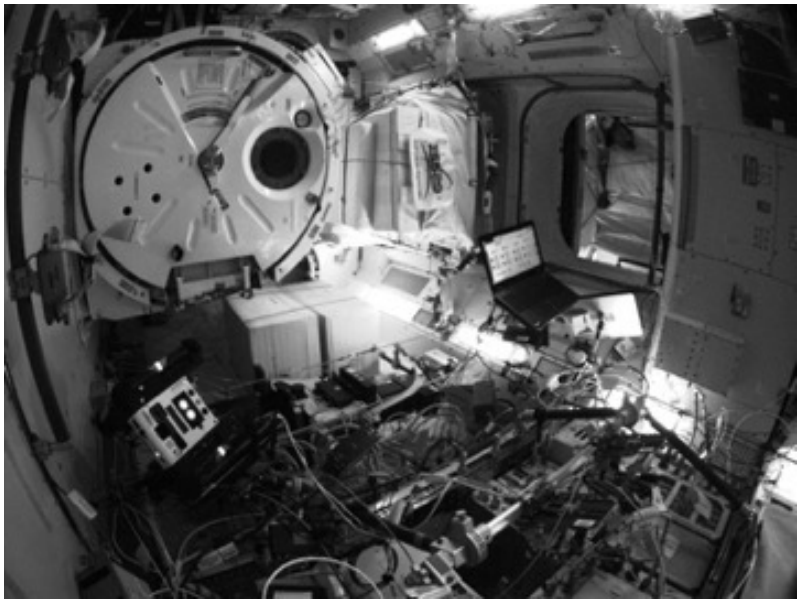
Dock Repair

- Lost communication with the Dock
- Root cause analysis pointed at corrupted memory card
- Dock designed for on-orbit repair
- Spare memory card launched as part of on-orbit spares
- Crew performed replacement
- Dock restored to functionality



Perching Demonstration

- Honey perched autonomously on 07/26/2021
- Perch location was also useful to see how Bumble had become entangled.
- Operator was able to use the view from Honey to free Bumble.

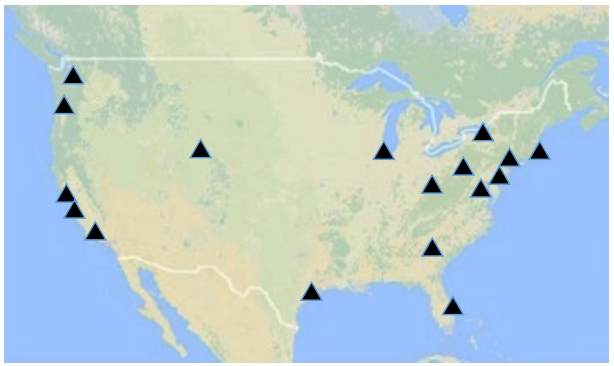


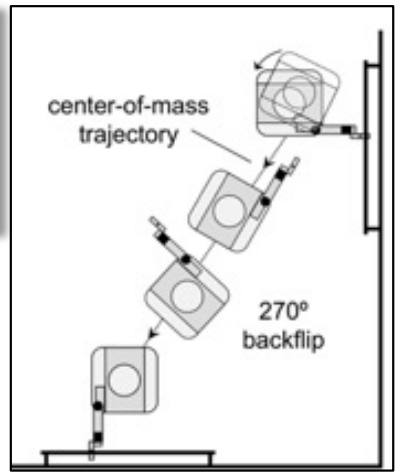
Completed Investigations

- Kibo Robotic Programming Competition – Year 1 – Completed 10/2020
- The REduced Gravity Gecko Adhesion docking Experiments (REGGAE) – Completed 01/2021
- Stanford Gecko – Phase 1 – Completed 04/2021

Ongoing Investigations

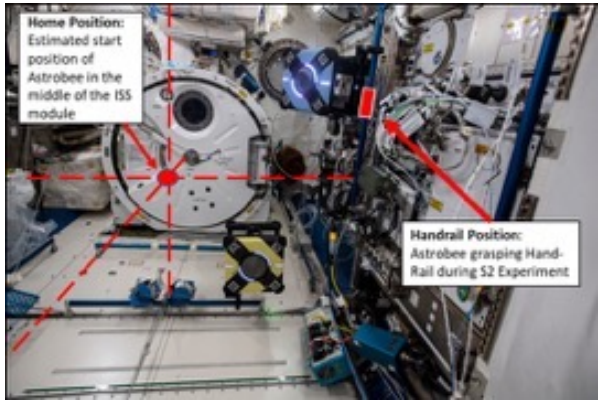
- Astrobatics (Naval Postgraduate School)
- SoundSee (Astrobotic/Bosch)
- Gecko (Stanford)
- RFID Recon (NASA AES/REALM-2)
- JAXA Kibo-RPC
- Astroporter (Tethers Unlimited)
- ISAAC (NASA STMD/GCD)
- ROAM (MIT/DLR)
- ReSWARM
- SVGS (FIT)
- SOARS (Zero-g Horizons)





Achievements

- 3 hours of continuous operation without crew intervention
- One Astrobee unit used to rescue a second
- 20 user sessions
- On-orbit repair of dock
- Autonomous Perching



(a) (b) (c) (d)

So long SPHERES

- SPHERES investigations completed
- Satellites are being down-massed
- Work in progress to have them displayed the Smithsonian

QUESTIONS?